Overview of groundwater in the Nile River Basin

Charlotte MacAlister, Paul Pavelic, Callist Tindimugaya, Tenalem Ayenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid

Key messages

- Groundwater is gaining increasing recognition as a vital and essential source of safe drinking water throughout the Nile Basin, and the demands in all human-related sectors are growing. The technical and regulatory frameworks to enable sustainable allocation and use of the resource, accounting for environmental service requirements, are largely not in place.

- The hydrogeological systems, and the communities they support, are highly heterogeneous across the basin, ranging from shallow local aquifers (which are actively replenished by rainfall recharge, meeting village-level domestic and agricultural needs) through to deep regional systems (which contain non-replenishable reserves being exploited on a large scale). A uniform approach to management under such circumstances is inappropriate.

- The database and monitoring systems to support groundwater management are weak or non-existent. With few exceptions, groundwater represents an unrecognized, shared resource among the Nile countries.

- Most Nile countries have strategic plans to regulate and manage groundwater resources but, so far, these largely remain on paper, and have not been implemented.

Introduction

Groundwater has always been essential for human survival throughout Africa, and this is the case in the Nile River Basin (NRB; UNEP, 2010). Traditionally, groundwater was accessed first at naturally occurring springs and seepage areas by humans and animals; later, as human ingenuity increased, it was accessed via hand-dug wells, advancing to hand-pumps and then to boreholes and mechanized pumps. Throughout the NRB we can see all of these forms of groundwater access in use today. As the population’s ability to develop and use technologies to access groundwater has grown, the scale of abstraction and human demand on groundwater resources has also increased. Maiyandima and Giordano (2007) provide a good overview of the exploitation of groundwater in Africa. Groundwater use the NRB includes domestic water supply in rural and urban settings for drinking and household use and small commercial activities; industrial use and development for tourism; agricultural use for irrigation and livestock production, from subsistence to cash crops, such as mineral exploration.

The overall type and characteristics such as extent of exploitation and sustainability depend largely on spatial and temporal variability in climate, and the same can be said for the quality of the water and its use. Groundwater is extensively utilized for agriculture and irrigation, and there is little data on the use of groundwater in Uganda and on the transboundary aspects.

This chapter provides an overview of groundwater resources in the Nile River Basin and provides a summary of current and potential use, potential, monitoring, policy and regulatory frameworks, and an overview of statistics on utilization and development. The regional hydrogeological setting of the continent scale. Various types of hydrogeological environments are present, including sedimentary rocks, unconsolidated and metamorphic rocks, basement rocks of varying age and are present as a result of several tectonic events. All these types of hydrogeological environments support groundwater recharge and storage, and they can be non-renewable or renewable depending on the conditions.Groundwater in Uganda is extensively utilized for agriculture and irrigation, and there is little data on the use of groundwater in Uganda and on the transboundary aspects.
Overview of groundwater in the Nile River Basin

Regional hydrogeology

The regional hydrogeological framework for the NRB and surrounding regions is well-defined as a result of several decades of effort resulting in the development of hydrogeological maps at the continent scale. Within the NRB (and the continent as a whole), there are four generalized types of hydrogeological environments: crystalline/metamorphic basement rocks, volcanic rocks, unconsolidated sediments and consolidated sedimentary rocks (Figure 10.1; Table 10.1; Foster, 1984; MacDonald and Calow, 2008).

Basement rocks comprise crystalline igneous and metamorphic rocks of the Precambrian age and are present across the area, but mainly in the upstream parts of the basin. With the exception of metamorphic rocks the parent material is essentially impermeable, and productive aquifers occur where weathered overburden and extensive fracturing are present. Consolidated sedimentary rocks are highly variable and can comprise low permeability mudstone and shale, as well as more permeable sandstones, limestones and dolomites. They tend to be present in the lower parts of the basin, forming some of the most extensive and productive aquifers. In the more arid regions, large sandstone aquifers have extensive storage, but much of the groundwater can be non-renewable, having originated in wetter, past climates. Unconsolidated sedimentary aquifers are present in many river valleys. Volcanic rocks occupy the NRB uplands (mainly the Ethiopian Highlands), where they form highly variable, and usually highly important, productive aquifers.
The Nile River Basin

Figure 10.1 Generalized hydrogeological domains of the Nile River Basin
Source: Adapted from MacDonald and Calow, 2008

The upstream NRB reaches of Uganda are characteristic of a crystalline bedrock setting. Here aquifers occur in the regolith (weathered rock) and in the fractured rock (unweathered), typically at greater depth. If the regolith thickness is large, weathered rock aquifers may have a good well yield; however, generally, the more productive aquifers are found in the contact zone between the two aquifer types. The regolith is typically at greater depth compared to the fractured bedrock, which may result in lower well yields due to shallower depth.
### Overview of groundwater in the Nile River Basin

#### Table 10.1 General characteristics of the aquifers within the Nile River Basin

<table>
<thead>
<tr>
<th>Country</th>
<th>Basin/region name</th>
<th>Hydrogeological environment</th>
<th>Depth (m)</th>
<th>Depth to SWL (m)</th>
<th>YIELD (l/s)</th>
<th>T (m²/d)</th>
<th>S (L/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGA</td>
<td>Country-wide</td>
<td>Basement rock + alluvial</td>
<td>0.2-13.9</td>
<td>16-34</td>
<td>0.011-0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETH</td>
<td>Abay Basin</td>
<td>Volcanic and basement</td>
<td>60-252</td>
<td>AR=138</td>
<td>0-2.5</td>
<td>31-2157</td>
<td></td>
</tr>
<tr>
<td>ETH</td>
<td>Abay and Baso-Akobo basins (northwest and west)</td>
<td>Dominantly volcanic</td>
<td>56-100</td>
<td>0.8-73</td>
<td>0.8-30</td>
<td>1-2630</td>
<td></td>
</tr>
<tr>
<td>ETH</td>
<td>Tekeze (north and northwest)</td>
<td>Volcanic, sedimentary and basement</td>
<td>51-180</td>
<td>32-168</td>
<td>0.0-2.5</td>
<td>32-240</td>
<td></td>
</tr>
<tr>
<td>SUD</td>
<td>El Gash</td>
<td>Unconsolidated (alluvial)</td>
<td>0.6-1.2</td>
<td>1000</td>
<td>10⁻⁵-10⁻³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUD</td>
<td>Bara</td>
<td>Detrital Quaternary &amp; Tertiary deposits</td>
<td>0.1-5.8</td>
<td>35-210</td>
<td>10⁻²-10⁻³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUD</td>
<td>Baggara</td>
<td>Detrital Quaternary &amp; Tertiary deposits</td>
<td>0.2</td>
<td>130-180</td>
<td>10⁻⁴-10⁻³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUD</td>
<td>Seleim</td>
<td>Consolidated (NSAS)</td>
<td>2.3-5.8</td>
<td>1500</td>
<td>10⁻⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUD</td>
<td>Khatroum</td>
<td>Consolidated (NSAS)</td>
<td>0.5-1.6</td>
<td>250</td>
<td>10⁻⁵-10⁻⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGY</td>
<td>Nile Delta</td>
<td>Unconsolidated</td>
<td>0-5</td>
<td>500</td>
<td>10⁻²</td>
<td>1400</td>
<td></td>
</tr>
<tr>
<td>EGY</td>
<td>Nile Valley</td>
<td>Unconsolidated</td>
<td>0-5</td>
<td>&lt;50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGY</td>
<td>Kharga</td>
<td>Consolidated (NSAS)</td>
<td>0-30</td>
<td>1000</td>
<td>10⁻²</td>
<td>2800</td>
<td></td>
</tr>
<tr>
<td>EGY</td>
<td>Nasser/Qintara</td>
<td>Consolidated (Mohga)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGY</td>
<td>Wadi Araba</td>
<td>Consolidated (Carbonate)</td>
<td>AR⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: SWL = standing water level; UGA = Uganda; ETH = Ethiopia; SUD = Sudan (North and South); EGY = Egypt; T = transmissivity; S = storativity; AR⁺ = artesian conditions; NSAS = Nubian Sandstone Aquifer System.

Sources: Authors' data; Tindimugaya, 2010; El Tahawi and Farag, 2008.*

... between the regolith and bedrock due to higher aquifer transmissivity associated with the coarser grain sizes and less secondary clay minerals. The highest yielding aquifers are the fractured bedrock if the degree of fracturing is high and hydraulically connected to the overlying regolith which, although low in permeability, provides some degree of storage and replenishment. The weathered aquifer is unconfined whereas the fractured-bedrock aquifer is leaky and the two aquifers form a two-layered aquifer system (Tindimugaya, 2008). Alluvial and fluvial aquifers are found adjacent to major surface water courses. The aquifers are found at relatively shallow depths, with average depths for shallow wells of 15 m and boreholes of 60 m. 

*189
The Nile River Basin

The hydrogeological setting in the Ethiopian part of the basin is extremely complex, with rock types ranging in age from Precambrian to Quaternary, with volcanic rocks most common in the highlands and the basement, and complex metamorphic and intrusive rocks in peripheral lowlands and a few highland areas (Chernet, 1993; Ayenew et al., 2008). Sedimentary rocks cover incised river valleys and most recent sediments cover much of the lowlands of all the major river sub-basins. The areas of Precambrian basement terrain are particularly complex due to various tectonic events. Groundwater flow systems, known from studies conducted in sub-basins such as Tekeze and Abay, suggest an intricate interaction of recharge and discharge, operating at local, intermediate and regional scales (Kebede et al., 2005). Springs are abundant at different topographic elevations, suggesting that the shallow groundwater operates under local flow systems controlled by static ground elevation. However, the thickness and lateral extent of the aquifers indicate that deeper, regional flow systems operate mainly in the volcanic and sedimentary rocks. Most of the Precambrian rocks have shallow aquifers. In these aquifers depth to groundwater level is not more than a few tens of meters. From a database of 1250 wells from across the country, Ayenew et al. (2008) showed that the yields of most shallow and intermediate aquifers do not exceed 5 l s⁻¹, whereas the highly permeable volcanoclastic deposits and fractured basalts of Addis Ababa and Debre Berehan areas, for example, can yield between 20 and 40 l s⁻¹, respectively. Recent drilling in deep volcanic aquifers has located highly productive aquifers, yielding over 100 l s⁻¹. Depth to the static water level in the unconfined aquifers in alluvial plains and narrow zones close to river beds do not normally exceed 10 m except in highland plains, where it is around 30 m. Seasonal water table fluctuations rarely exceed 2 m.

Groundwater in the Sudanese part of the NRB lies within a multi-structural system of rifts, which range in age from the Paleozoic through to the most recent Quaternary and have resulted from the accumulation and filling with consolidated and unconsolidated sediments. Rift structures in Sudan also act as reservoirs for hydrocarbon reserves at greater depths. The major hydrogeological formations in Sudan include the Nubian Sandstone Aquifer System (NSAS), the Umm Ruwaba, Gezira sedimentary aquifer, the unconsolidated alluvium fluvial (seasonal streams) and wadis, and the Basement Complex aquifers. The NSAS may attain a thickness of 500 m, and is found under water table (unconfined) conditions or semi-confined artesian conditions. In some areas (e.g. northern Darfur), the NSAS is overlain by volcanic rocks. The Umm Ruwaba sediments are characterized by thick deposits of clay and clayey sands under semi-confined to confined conditions. The Basement Complex, extending over half of Sudan, is a very important source of groundwater. Unless subjected to extensive weathering, jointing and fracturing the parent rock is largely impervious. In the White and Blue Nile sub-basin sands and gravels in the Gezira and El Atshan Formations constitute important aquifers. Quaternary and recent unconfined aquifers tend to comprise a few metres of sand, silt and clay as well as gravel.

In Egypt, the major aquifers are generally formed of either unconsolidated or consolidated granular (sand and gravel) material or in fissured and karstified limestone. The hydrogeological provinces present within the NRB include the Nile Valley and Delta aquifers, Nubian sandstone aquifer, Moghra aquifer, tertiay aquifer, carbonate rock aquifers and fissured basement aquifers. The hydrogeological characteristics and extent of each hydrogeological unit are generally well known. The Nile Valley aquifer, confined to the floodplain of the Nile River system, consists of fluvial and reworked sand, silt and clay under unconfined or semi-confined conditions (Omer and Isawi, 1998). The saturated thickness varies from a few metres through to 300 m. This high storage capacity, combined with high transmissivity (5000–20,000 m² day⁻¹) and active replenishment from the river and irrigation canals makes the aquifer a highly valued
GROUNDWATER QUALITY AND SUITABILITY FOR USE

Data on groundwater quality in the NR B vary widely from country to country, but are generally restricted to the major constituents with a few exceptions. Time series are largely absent, except in Egypt where a groundwater quality monitoring network is well established (Tawood, 2004), and more generally when associated with monitoring of public water supply wells (qauna and Roehoff, 2004). Spatial coverage is limited. Based on the available data, groundwater quality is known to be highly variable and influenced by the hydrogeological environment (granular, hard rock), type of water sources (tube wells, dug wells, springs) and level of anthropogenic influence.

In the Ugandan part of the basin, groundwater quality in most areas meets the guideline requirements for drinking water with the exception of iron and manganese in highly corrosive low pH groundwater, and nitrates in densely populated areas associated with poor sanitation (IGS, 2001). In chemical terms, the groundwater is fresh, and contains a mixture of calcium-magnesium sulphate and calcium-magnesium bicarbonate types of water, which result from differences in the water-rock interactions. Generally, calcium bicarbonate groundwaters are younger and found under phreatic conditions, whereas calcium sulphate waters are older (Tweed et al., 2005).

Generally groundwater quality is naturally good throughout the Blue Nile Basin (BNB), with freshwater suitable for multiple uses (Table 10.2). There are some localized exceptions, including salinity due to mineralization arising from more reactive rock types or from pollution due to urbanization, particularly underlying areas of highly permeable unconsolidated sediments in waters drawn from hand-dug wells and unprotected springs (Demile and Wohnlisch, 2006). The groundwater is dominantly fresh with total dissolved solid levels less than 200 mg l^-1, with pockets of elevated salinity evident in deep boreholes due to the presence of gypsum in sedimentary rocks of the Tekeze sub-basin and in the Tana sub-basin (Afsaw, 2003; Aynew, 2005). Hydrochemical facies include bicarbonate, sulphate and chloride types, with calcium and magnesium being the dominant cations bringing associated hardness to the water.
The amount of the solute content depends on the residence time of groundwater and the mineral composition of the aquifer resulting in, for example, elevated mineral/salinity content in deep sedimentary aquifers due to extended residence times. Naturally high levels of hydrogen sulphide and ammonia can be present in deep anaerobic environments or shallow organic carbon-rich (swampy) areas and cause problems of taste and odour.

Fluoride is a major water-related health concern and is present at levels above drinking water standards in a number of localities, particularly in the western highlands, including waters emanating from hot springs (Kloos and Tekle-Haimanot, 1999; Ayenew, 2008) and within the Ethiopian rift volcanic terrain, adjacent to the NRB. Ethiopia recognizes the issue of high localized levels of fluoride in groundwater (e.g. Jimma) and is hosting the National Fluorosis Mitigation Project (NFMP). According to the Ministry of Health and United Nations Children's Fund (UNICEF), 62 per cent of the country's population are iodine-deficient. Nitrate contamination of groundwater, derived mainly from anthropogenic sources including sewerage systems and agriculture (animal breeding and fertilizers), is already a problem in rural and urban centres. This is worst in urban areas close to shallow aquifers. High nitrate concentrations thought to originate from septic tank effluents have been detected in several urban areas including Bahirdar, Desie and Mekele (Ayenew, 2005). Several small towns and villages utilizing shallow groundwater via hand-dug wells have reported problems of nitrate pollution from septic pits (Alemayehu et al., 2005).

The most common source of poor water quality in groundwater (and surface water) in Ethiopia is microbiological contamination, primarily by coliform bacteria. Poor management of latrine pits and septic systems in both rural and urban areas continues to lead to faecal contamination of groundwater, for example, digging septic pits too close to drinking water wells. Many urban populations still rely on hand-dug wells and unprotected springs as a drinking water source and these are frequently contaminated. The Ministry of Water Resources is developing national water quality guidelines. However, enforcement of any guidelines will need to be backed up by extensive training and education campaigns at all levels in rural and urban areas.

Within North and South Sudan, Nubian aquifers are considered to contain the best quality groundwater and are generally suitable for all purposes. The salinity of the groundwater varies from 80 to 1800 mg l\(^{-1}\). More saline water is associated with down-gradient areas having enhanced residence times; shallow water table areas due to enrichment from evaporation and evapotranspiration, mineralization from claystones, mudstones, basals, dissolution from salt-bearing formations and mixing with overlying Tertiary and Quaternary aquifers. Nubian groundwater is mainly sodium bicarbonate type, with calcium or magnesium bicarbonate waters common near the recharge zones. The salinity of the Umm Ruwaba sedimentary formation, the second most important groundwater source after the NSAS, is generally good but may rise to over 5000 mg l\(^{-1}\) along the margins. Groundwater quality is a major determinant in location and type of groundwater development that can take place. In one of the few reported studies on groundwater quality in Sudan, groundwater production wells in Khartoum State, east of the Nile and the Blue Nile rivers, reveal the NSAS groundwater is largely fit for human and irrigation purposes except at a few localities, due to elevated major ion levels (Ahmed et al., 2000). Groundwater quality tends to be measured only in association with development activities to test suitability and ensure human health.

Within the Nile Valley region in Egypt, groundwater is of good quality (<1500 mg l\(^{-1}\) total dissolved solids, TDS, and mainly used for irrigation and domestic purposes; El Tahlawy and Farrag, 2008). In the valley margins remote from surface water systems to the east and west, the groundwater salinity tends to be more elevated (Hefny et al., 1992). The groundwater in the
Overview of groundwater in the Nile River Basin

Table 10.2 Groundwater quality at three locations in the Nile Basin

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Blue Nile (Abay)</th>
<th>Blue Nile sub-basin, Sudan</th>
<th>Western Desert, Egypt</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.99</td>
<td>8.0</td>
<td>6.39</td>
</tr>
<tr>
<td>TDS</td>
<td>366</td>
<td>340</td>
<td>351</td>
</tr>
<tr>
<td>Sodium</td>
<td>10</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>49</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>Magnesium</td>
<td>10</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>Potassium</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>160</td>
<td>200</td>
<td>58</td>
</tr>
<tr>
<td>Chloride</td>
<td>20.5</td>
<td>24</td>
<td>90.8</td>
</tr>
<tr>
<td>Carbonate</td>
<td>9.5</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td>9</td>
<td>18</td>
<td>53</td>
</tr>
<tr>
<td>Phosphate</td>
<td>47</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>47</td>
<td>–</td>
<td>1.0</td>
</tr>
<tr>
<td>Silica</td>
<td>40</td>
<td>–</td>
<td>7.5</td>
</tr>
<tr>
<td>Phosphate</td>
<td>–</td>
<td>–</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Notes: *Units are mg L⁻¹, except for pH
  * median value quoted, n = 13
  * Al-Atshan aquifer from Hussein, 2004
  * NSAS, Dakhla Oasis, n = 10 from Soban, 1999

Groundwater recharge rates, distribution and processes

Sustainable development of groundwater resources is strongly dependent on a quantitative knowledge of the rates at which groundwater systems are being replenished. A reasonably clear picture of the distribution of recharge rates across the NRB has recently begun to emerge. Using satellite data from the Gravity Recovery and Climate Experiment (GRACE), supported by recharge estimates derived from a distributed recharge model, Bonsor et al. (2010) found values ranging from less than 50 mm yr⁻¹ in the semi-arid lower (as well as upper) catchments, and a mean of 250 mm yr⁻¹ in the subtropical upper catchments (Figure 10.2). Along the thin riparian valley strips recharge from surface water and irrigation seepage may be up to 400 mm yr⁻¹. The total annual recharge within the basin has been estimated at about 130 mm, or 400
km$^3$ in volumetric terms. High temporal and spatial rainfall variability within the basin, when combined with the contrasting surface geology, accounts for this large range and generally low rates of groundwater replenishment. Values derived from the handful of local field studies, used as independent checks, are within this range (0-200 mm yr$^{-1}$). At the African scale, based on a 50x50 km grid resolution, Döll and Fiedler (2008) determined recharge to range from 0 to 200 mm yr$^{-1}$ across the NRB with similar magnitudes and patterns to those later reported by Bonsor et al. (2010).

There have been a number of regional and local-scale recharge studies employing a variety of methods to arrive at groundwater recharge fluxes. An annual groundwater recharge in the order of 200 mm yr$^{-1}$, for the 840 km$^2$ Arua catchment of the Victoria Nile, central Uganda, was determined by Taylor and Howard (1996) using a soil moisture balance model and isotope data. In several of the upper subcatchments of the Blue Nile, Ethiopia, recharge was estimated at less than 50 mm yr$^{-1}$ in arid plains and up to 400 mm yr$^{-1}$ in the highland areas of northwestern Ethiopia, using a conventional water balance approach and river discharge analysis, chloride mass balance, soil-water balance methods and river or channel flow losses (Ayenew et al., 2007). Bonsor et al. (2010) report groundwater recharge in the Singida region of northern Tanzania to be 10-50 mm yr$^{-1}$. In the upper subcatchments, studies consistently revealed that groundwater recharge varies considerably in space and time in relation to differences in the distribution and amount of rainfall, the permeability of rocks, geomorphology and the availability of surface water bodies close to major unconfined and semi-confined aquifers that feed the groundwater. Across the landscape, large differences are observed in recharge between the lowlands, escarpments and highlands (Chernet, 1993; Ayenew, 1998; Kebede et al., 2005).

Within the Nile Valley areas of Egypt, the Quaternary aquifer is recharged mainly from the irrigation canals that play an essential role in the configuration of the water table. The aquifer is recharged by infiltration from the irrigation distribution system and excess applications of irrigation water, with some of this returned to the Nile River.

Palaeo-groundwater is a vast resource in the more arid lower reaches of the basin. The NSAS...
variability within the basin, when this range and generally low
handful of local field studies, used

charge studies employing a variety
ulgroundwater recharge in the
the Victoria Nile, central Uganda,
so balance model and isotope
Ethiopia, recharge was estimated
in the highland areas of north-
channel and river discharge analysis,
channel flow losses (Ayenew et
the Singida region of northern
age estimate of just 6 mm yr$^{-1}$ is
alla (2010) determined recharge
10 mm yr$^{-1}$ at distances 20–30
able isotope composition of
sub-basins and determined the
be minimal, with much of the
eastern desert region of Egypt,
t of the rainfall in high rainfall
in wadis that replenish the allu-

It of the rainfall in high rainfall

In the more recent work of Owor
ies receive preferentially high
returns to areas under irrigi-
order of around 400 mm yr$^{-1}$

it revealed that groundwater
reres in the distribution and
and the availability of surface
rs that feed the groundwater.
tween the lowlands, escarp-

is recharged mainly from the
play an essential role in the
filtration from the irrigation
with some of this returned to
ches of the basin. The NSAS

is considered an important groundwater source, but this is fossil groundwater and non-renewable
due to both limited modern-day recharge and the long travel time. It has been suggested that in
Pleistocene times, when more humid climatic conditions prevailed, that the NSAS was
recharged by meteoric waters (Isa3 et al., 1972). The NSAS is found at depths and so is expen-
sive to develop and the pumping and delivery infrastructures are also expensive to maintain.
Under circumstances where the groundwater resource is poorly replenished or non-renewable,
as is common across more arid environments, concepts of sustainable development must be
revisited, with the intensive use of groundwater a contentious issue (Abderrahman, 2003).
Groundwater utilization and development

Throughout the NRB as a whole, the level of use or exploitation of groundwater varies widely. Groundwater is essential for drinking and for domestic water supply in most of the basin, while the use of groundwater to irrigate agricultural areas is primarily driven by the amount of rainfall and by the ease of access to, and supply of, surface waters. In the Upper Blue Nile catchment of Ethiopia, where rainfall is generally high (although seasonal droughts occur), groundwater extraction for agriculture is low compared with some areas of Egypt and Sudan where the resource is extensively developed. In some cases, the abstraction rate exceeds recharge (e.g. Gash, Sudan; see Table 10.1). Knowledge and data on groundwater use vary widely within the Nile countries (see 'Monitoring and assessment of groundwater resources' later in this chapter), although more readily available information naturally exists in those countries which rely heavily on groundwater, such as Egypt and Sudan. In the following sections we focus on four Nile countries: Uganda, Ethiopia, Sudan and Egypt.

Uganda

Historically, small-scale groundwater abstraction is widespread in Uganda, and more intensive development has been ongoing since the early twentieth century. However, abstraction remains relatively small scale when compared with potential supply, with groundwater utilized largely to satisfy rural and urban domestic demand. This is because most of Uganda has a ready supply of rainfall and surface water including large water bodies and widespread wetland areas, many of which are groundwater-fed.

Throughout Uganda, aquifers are found at relatively shallow depths (average 15 m) and the 'deep' boreholes are small-diameter wells deeper than 30 m (average 60 m). Shallow wells (less than 30 m, with an average depth of 15 m) are constructed in the unconsolidated formation. Boreholes and shallow wells are normally installed with hand pumps with a capacity of 1 m$^3$ hr$^{-1}$ and their yields commonly range between 0.5 and 5 m$^3$ hr$^{-1}$. Since the early 1990s, there has been an increase in intensive groundwater abstraction for urban water supplies, utilizing high-quality groundwater with little or no treatment costs when compared with surface water. Boreholes with yields greater than 3 m$^3$ hr$^{-1}$ are normally considered as suitable for piped water supply and installed with motorized pumps. In recent drilling of high-yielding boreholes in former river channels, yields of more than 20 m$^3$ hr$^{-1}$ have been achieved. There are an estimated 20,000 deep boreholes, 3000 shallow wells and 12,000 protected springs in the country, utilized mainly for rural domestic water supply. Approximately 40,000 additional boreholes and 20,000 shallow wells are needed to provide 100 per cent rural water supply coverage (Tindimugaya, 2010).

While agriculture dominates the Ugandan economy, this is mostly smallholder rain-fed subsistence farming and irrigation is not widespread largely due to high investment costs, unsure returns, and lack of capacity. Most irrigation utilizes surface water with some limited upland horticulture crop irrigation using small-scale pumping systems. Traditionally, mineral-rich groundwater-fed wetlands with shallow water tables were utilized for rice production (with water tables managed in some cases for other crops) but this is now limited by the Ministry of Water, Lands and Environment (MWLE) in recognition of the ecosystem services and biodiversity value of wetlands.

Agricultural use of groundwater in Uganda is predominantly for the watering of livestock. However, figures which quantify this supply are very limited. According to MWLE figures (MWLE, 2006), approximately 20 deep boreholes, yielding an average of 8 m$^3$ hr$^{-1}$, have been
Overview of groundwater in the Nile River Basin

construction and installed with pumping windmills for livestock watering in northeastern Uganda. There is very little evidence of the utilization of groundwater to irrigate fodder crops or crop with residue used as animal feed, which would otherwise constitute the largest part of livestock water demand.

Ethiopia

Throughout the Ethiopian BNB groundwater is the most common source of domestic water, supplying at least 70 per cent of the population. In the rugged mountainous region of the Ethiopian Highlands, settlement patterns of rural communities are determined largely by the distribution of springs. The depth to water table in most highland plains is less than 30 m. In the alluvial plains and narrow zones close to river beds, depth to the static water level in the unconfined aquifers does not normally exceed 10 m. These aquifers are the most commonly utilized water source for rural communities. In both cases, seasonal water table fluctuation is not thought to exceed 2 m (Ayenew et al., 2008). Groundwater for domestic use is commonly utilized via springs, shallow hand-dug wells, sometimes fitted with manual pumps, and in some cases, boreholes. In urban centres deep boreholes normally provide water for both drinking and industrial purposes. Over 70 per cent of the large towns in the basin depend on intermediate to deep boreholes fitted with submersible pumps and in some cases, large fault-controlled high discharge springs.

Generally, groundwater quality is naturally good and suitable for multiple uses throughout the BNB. There are some naturally occurring areas of high total dissolved solids and locally high salinity, sulphides, metals and arsenic, but the main concerns for water quality are fluoride, iodine and man-made, point source pollution including nitrates and coliform bacteria.

Despite the importance of groundwater to the majority of the population, it was given very limited attention in planning and legislation in the past, although this is now changing. The demand for domestic water supply from groundwater has been increasingly achieved over the last two decades but will continue to increase and plans to expand access are ongoing (Table 10.3).

Table 10.3 Estimate of rural population supplied with domestic water from groundwater in Ethiopia: 2008 figures and planned improvements to be implemented by 2012

<table>
<thead>
<tr>
<th>Region</th>
<th>Tigray</th>
<th>Gambella</th>
<th>Benishangul Gumuz</th>
<th>Amhara</th>
<th>Oromia</th>
<th>National</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population in 2007 (million)</td>
<td>4.3</td>
<td>0.31</td>
<td>0.67</td>
<td>17.2</td>
<td>27.2</td>
<td>74</td>
</tr>
<tr>
<td>Population supplied from groundwater (million)</td>
<td>2.05</td>
<td>0.1</td>
<td>0.26</td>
<td>8.6</td>
<td>12.6</td>
<td>34.4</td>
</tr>
<tr>
<td>Percentage of population supplied</td>
<td>58</td>
<td>39</td>
<td>44</td>
<td>56</td>
<td>51</td>
<td>54</td>
</tr>
<tr>
<td>Percentage supply planned for 2012</td>
<td>109</td>
<td>94</td>
<td>89</td>
<td>118</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Number of groundwater schemes planned 2009-12</td>
<td>7928</td>
<td>610</td>
<td>1428</td>
<td>37,468</td>
<td>26,093</td>
<td>110,460</td>
</tr>
</tbody>
</table>


development

itation of groundwater varies widely. In the Upper Blue Nile (although seasonal droughts occur), with some areas of Egypt and Sudan, the abstraction rate exceeds 1d data on groundwater use vary assessment of groundwater resources' tion naturally exists in those coun- and Egypt.

d in Uganda, and more intensive r. However, abstraction remains high groundwater utilized largely at of Uganda has a ready supply widespread wetland areas, many of depths (average 15 m) and the erage 60 m). Shallow wells (the unconsolidated formation, pumps with a capacity of 1 m('). Since the early 1990s, there urban water supplies, utilizing compared with surface water, and as suitable for piped water of 'the . . . high-yielding boreholes in en achieved. There are an esti-ctected springs in the country, 0,000 additional boreholes and rural water supply coverage mostly smallholder rain-fed to high investment costs, ace water with some limited items. Traditionally, mineral-utilized for rice production: this is now limited by the on of the ecosystem services in the watering of livestock: according to MWLE figures age of 8 m' hr('), have been

To the lowmg sections...
Currently, direct groundwater utilization for irrigated agriculture is marginal. This mostly takes the form of shallow wells close to rivers, and in some cases, downstream of micro-dams and sand dams, constructed to effectively recharge groundwater. Generally, a well yield of 21 m³ is considered adequate to irrigate one hectare. This is mostly supplemental irrigation of cash crops. While surface water irrigation is more common, the groundwater baseflow contribution to river flow should not be ignored. This is a significant component, and, without it, abstraction for irrigation, especially supplemental irrigation in dry periods, would be impossible. Generally, a well yield of 21 m³ is considered adequate to irrigate one hectare. This is mostly supplemental irrigation of cash crops. While surface water irrigation is more common, the groundwater baseflow contribution to river flow should not be ignored. This is a significant component, and, without it, abstraction for irrigation, especially supplemental irrigation in dry periods, would be impossible. Generally, a well yield of 21 m³ is considered adequate to irrigate one hectare.

Groundwater is essential for livestock production in Ethiopia, primarily for drinking as opposed to feed or forage production. Farmers and pastoralists access groundwater all year-round to water livestock. At the time of writing, North and South Sudan have undergone a process of separation after years of civil war. While government structures remain in place in North Sudan, and new Ministries are evolving in South Sudan, it is very difficult to access official ‘government’ figures externally, and most figures which can be accessed are in an unpublished form. Much of the recent published information relates to aid and donor missions, with a particular focus on water supply (e.g. Michael and Gray, 2005; Pact, 2008). When viewed in this context, the range of values can be found for annual abstraction rates (Ibrahim, 2010), from 1 billion m³ to more than double this when agricultural and domestic uses are combined. Annual recharge is estimated at around 2.3 billion m³. Throughout Sudan, groundwater is accessed for drinking and domestic water supplies. While 70 per cent of groundwater abstraction in Sudan is reported to be for irrigation, groundwater constitutes around 50 per cent of urban and 80 per cent of rural domestic water supply (Ibrahim, 2010). At the time of writing, North and South Sudan have just undergone a process of separation after years of civil war. While government structures remain in place in North Sudan, and new Ministries are evolving in South Sudan, it is very difficult to access official ‘government’ figures externally, and most figures which can be accessed are in an unpublished form. Much of the recent published information relates to aid and donor missions, with a particular focus on water supply (e.g. Michael and Gray, 2005; Pact, 2008). When viewed in this context, the range of values can be found for annual abstraction rates (Ibrahim, 2010), from 1 billion m³ to more than double this when agricultural and domestic uses are combined. Annual recharge is estimated at around 2.3 billion m³. Throughout Sudan, groundwater is accessed for drinking and domestic water supplies. While 70 per cent of groundwater abstraction in Sudan is reported to be for irrigation, groundwater constitutes around 50 per cent of urban and 80 per cent of rural domestic water supply (Ibrahim, 2010). At the time of writing, North and South Sudan have just undergone a process of separation after years of civil war. While government structures remain in place in North Sudan, and new Ministries are evolving in South Sudan, it is very difficult to access official ‘government’ figures externally, and most figures which can be accessed are in an unpublished form. Much of the recent published information relates to aid and donor missions, with a particular focus on water supply (e.g. Michael and Gray, 2005; Pact, 2008). When viewed in this context, the range of values can be found for annual abstraction rates (Ibrahim, 2010), from 1 billion m³ to more than double this when agricultural and domestic uses are combined. Annual recharge is estimated at around 2.3 billion m³. Throughout Sudan, groundwater is accessed for drinking and domestic water supplies. While 70 per cent of groundwater abstraction in Sudan is reported to be for irrigation, groundwater constitutes around 50 per cent of urban and 80 per cent of rural domestic water supply (Ibrahim, 2010). At the time of writing, North and South Sudan have just undergone a process of separation after years of civil war. While government structures remain in place in North Sudan, and new Ministries are evolving in South Sudan, it is very difficult to access official ‘government’ figures externally, and most figures which can be accessed are in an unpublished form. Much of the recent published information relates to aid and donor missions, with a particular focus on water supply (e.g. Michael and Gray, 2005; Pact, 2008).
Groundwater is essential for agriculture in Sudan. According to the Ministry of Irrigation and Water Resources, around 875 million m$^3$ are utilized annually for irrigation. The fertile soils found along the Nile floodplain and seasonal streams are irrigated using both the Nile surface water and groundwater. Groundwater is used to irrigate fruit and vegetables via a range of abstraction methods. Where individual plots do not exceed 4.2 ha, hand-dug wells or ‘matars’ (hand-dug wells with pipes driven in) fitted with centrifugal pumps are common. Most plots are associated with fertile and easily cultivated floodplains with shallow, annually replenished water tables and low construction costs. Boreholes are also used for irrigation in some areas, either exclusively or to supplement surface water and rainwater.

### Table 10.4: Groundwater utilization for domestic supply throughout North and South Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Urban (%)</th>
<th>Rural (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khartoum</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Northern</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Eastern</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Central</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Kordofan</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Darfur</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>South Sudan</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Average</td>
<td>51</td>
<td>79</td>
</tr>
<tr>
<td>Total supply (million m$^3$ yr$^{-1}$)</td>
<td>800</td>
<td>300</td>
</tr>
</tbody>
</table>

Source: Ibrahim, 2009
The Nile River Basin

There are numerous methods of groundwater abstraction in Sudan, determined mostly by the depth to water level, intended use, access to main electric supply and resources available. In rural areas open hand-dug wells are common, with water drawn by a rope-and-bucket system by hand, animal-power or windlass depending on depth. Technologies in drilled wells for domestic or agricultural use range from reciprocating hand-pumps, centrifugal pumps driven by electrical motors or diesel engines and electrical submersible diesel-engine-driven vertical turbine pumps.

Livestock contribute a significant additional agricultural water demand, particularly in less-fertile areas away from river valleys. The livestock population is estimated at around 140 million head (compared with a population of 45 million) concentrated mainly in southern, central and western Sudan, and annual groundwater abstracted for livestock watering is estimated at 400 million m³. Groundwater also contributes to livestock water demand through production of fodder crops and crop residue for feed.

Table 10.5 illustrates the distribution of abstraction rates and well type in different areas irrigated with groundwater in both North and South Sudan.

<table>
<thead>
<tr>
<th>State</th>
<th>Locality</th>
<th>Area (ha)</th>
<th>Abstraction (million m³/yr)</th>
<th>Well type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern El Seleim</td>
<td></td>
<td>20,090</td>
<td>345</td>
<td>Matar</td>
</tr>
<tr>
<td>Northern Latit Basin</td>
<td></td>
<td>5000</td>
<td>115</td>
<td>Matar</td>
</tr>
<tr>
<td>Nile</td>
<td>Lower Atbara Basin</td>
<td>1430</td>
<td>40</td>
<td>Matar</td>
</tr>
<tr>
<td>Kassala</td>
<td>Gash Basin</td>
<td>6200</td>
<td>145</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Gezira</td>
<td>North Gezira</td>
<td>1500</td>
<td>40</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Khartoum</td>
<td>Khartoum area</td>
<td>5000</td>
<td>120</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>North Kordofan</td>
<td>Bara area</td>
<td>1430</td>
<td>8</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>North Kordofan</td>
<td>Khor Abu Habel</td>
<td>1400</td>
<td>5</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>South Kordofan</td>
<td>Abu Kerhoela</td>
<td>4000</td>
<td>7</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>South Kordofan</td>
<td>Area</td>
<td>1000</td>
<td>3</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>Gezira Marra</td>
<td>W Assam</td>
<td>3000</td>
<td>10</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Gezira Marra</td>
<td>Jebel Marra area</td>
<td>2900</td>
<td>15</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>North Darfur</td>
<td>Kabakabia</td>
<td>1430</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>North Darfur</td>
<td>Wadi Kutum</td>
<td>1400</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>West Darfur</td>
<td>Wadi Gemena</td>
<td>950</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>South Darfur</td>
<td>Wadi Nyala</td>
<td>1400</td>
<td>8</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>58,040</td>
<td>876</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ibrahim, 2009

North and South Sudan combined are estimated to have approximately 82 million ha of land suitable for arable production (one-third of the total combined area), of which around 21 per cent is currently under cultivation. In addition to the irrigated areas included in Table 10.5, 1.4 million ha of agricultural land across North and South Sudan were classified by the previous government as eligible for supplementary or complete irrigation by groundwater. Given that only 0.06 million ha out of 82 million ha of suitable arable land seem to be irrigated with groundwater, it is evident that development of schemes to utilize this large resource is needed to contribute to civil welfare and economic development.

Currently, it is estimated that the total groundwater demand is 55.5 billion cubic meters (Attia, 2007) in Sudan, of which around 42 billion m³ is estimated to be supplied from non-rechargeable unconfined aquifers, and in excess of 7 billion m³ from the Nubian Aquifer to Libya, Saudi Arabia and Egypt.

For the irrigated areas across Eastern, Southern, and Western Sudan, Table 10.5 illustrates the distribution of abstraction rates and well type in different areas irrigated with groundwater in both North and South Sudan.

Table 10.5 Areas irrigated with groundwater in North and South Sudan

<table>
<thead>
<tr>
<th>State</th>
<th>Locality</th>
<th>Area (ha)</th>
<th>Abstraction (million m³/yr)</th>
<th>Well type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern El Seleim</td>
<td></td>
<td>20,090</td>
<td>345</td>
<td>Matar</td>
</tr>
<tr>
<td>Northern Latit Basin</td>
<td></td>
<td>5000</td>
<td>115</td>
<td>Matar</td>
</tr>
<tr>
<td>Nile</td>
<td>Lower Atbara Basin</td>
<td>1430</td>
<td>40</td>
<td>Matar</td>
</tr>
<tr>
<td>Kassala</td>
<td>Gash Basin</td>
<td>6200</td>
<td>145</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Gezira</td>
<td>North Gezira</td>
<td>1500</td>
<td>40</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Khartoum</td>
<td>Khartoum area</td>
<td>5000</td>
<td>120</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>North Kordofan</td>
<td>Bara area</td>
<td>1430</td>
<td>8</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>North Kordofan</td>
<td>Khor Abu Habel</td>
<td>1400</td>
<td>5</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>South Kordofan</td>
<td>Abu Kerhoela</td>
<td>4000</td>
<td>7</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>South Kordofan</td>
<td>Area</td>
<td>1000</td>
<td>3</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>Gezira Marra</td>
<td>W Assam</td>
<td>3000</td>
<td>10</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Gezira Marra</td>
<td>Jebel Marra area</td>
<td>2900</td>
<td>15</td>
<td>Hand-dug</td>
</tr>
<tr>
<td>North Darfur</td>
<td>Kabakabia</td>
<td>1430</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>North Darfur</td>
<td>Wadi Kutum</td>
<td>1400</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>West Darfur</td>
<td>Wadi Gemena</td>
<td>950</td>
<td>5</td>
<td>Matar</td>
</tr>
<tr>
<td>South Darfur</td>
<td>Wadi Nyala</td>
<td>1400</td>
<td>8</td>
<td>Matar + borehole</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>58,040</td>
<td>876</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ibrahim, 2009
in Sudan, determined mostly by supply and resources available. In
by a rope-and-bucket system technologies in drilled wells for
pumps, centrifugal pumps driven
diesel-engine-driven vertical
drill water demand, particularly in less-
ated at around 140 million
mainly in southern, central and
watering is estimated at 400
through production of
well type in different areas irri-
ne currently, it is likely that, at some point in the near future, resources will be found
to develop this resource and groundwater abstraction will increase significantly. A number of
schemes were planned in the 1990s to produce food for export to Gulf states, and with the end
to civil war, it is likely that such ventures will once more become viable.

Currently, the total annual water requirement of all socio-economic sectors in Egypt is esti-
med to be 76 billion m$^3$ yr$^{-1}$, of which the agriculture sector alone requires 82 per cent
(Attia, 2002). Egypt relies heavily on surface water from the Nile, with an annual quota of
55.5 billion m$^3$ yr$^{-1}$ allocated according to the 1959 agreement between Egypt and Sudan.
The total harvestable national run-off is around 1.3 billion m$^3$ yr$^{-1}$ and the remainder of the
demand must be satisfied by using groundwater. The two most important groundwater
aquifers are the NSAS of the Western Desert, and Nile Valley and Delta system. The deep and
non-renewable fossil water of the NSAS covers about 65 per cent of Egypt and extends into
Libya, Sudan and Chad.

Clearly, Egypt's demand already exceeds its apparent supply and this is likely to be exacer-
bated in the future with increasing demand for expanding agriculture, population growth,
urbanization and higher living standards. As the volume of surface water from the Nile cannot
be guaranteed with shifting regional politics and uncertainties, groundwater exploitation will
undoubtedly accelerate.

There are known to be more than 31,410 productive deep wells and 1722 observation wells
distributed throughout the Nile Delta, Nile Valley, coastal zone, oases and Darb El Arbaïn, and
Eastern Oweinat. These include wells for domestic and agricultural supply. Tables 10.6 and 10.7
illustrate extraction rates, use and potential, and distribution of wells.

<table>
<thead>
<tr>
<th>Location</th>
<th>Production wells</th>
<th>Abstraction (million m$^3$ yr$^{-1}$)</th>
<th>Observation wells</th>
<th>Potential (million m$^3$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern West Coastal Zone and Siwa</td>
<td>1000</td>
<td>149</td>
<td>1</td>
<td>194</td>
</tr>
<tr>
<td>Nile Delta and Nile Valley</td>
<td>27,300</td>
<td>5</td>
<td>1704</td>
<td>500</td>
</tr>
<tr>
<td>Zone of Lake Nasser</td>
<td></td>
<td>0.05</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Western Desert, Oases and Darb El Arbaïn</td>
<td>3100</td>
<td>1108</td>
<td>13</td>
<td>2246</td>
</tr>
<tr>
<td>Eastern Oweinat</td>
<td>50</td>
<td>390</td>
<td>4</td>
<td>1210</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1713.05</td>
<td></td>
<td>4271</td>
</tr>
</tbody>
</table>

Sources: Heiny and Sahta, 2004; MWRI, 2010

Generally, domestic water is obtained from deep wells (>800 m) of naturally good quality.
In urban areas, all houses are connected to a mains supply, while around 40 per cent of rural
communities are reported to be connected, but large portions of the rural population still
depend on water collected from small waterways. Small-capacity private wells are also common
at the household level although many are in a poor condition. In the newly settled areas, most
The Nile River Basin

wells are managed by the Ministry of Housing and New Communities or are under the local
unities in old towns and villages.

The 82 per cent of Egypt’s water demand required for agriculture refers to the irrigation of
existing cultivated areas, newly irrigated land reclaimed from the desert, and improved drainage
and irrigation conditions. While approximately 70 per cent of this demand is satisfied by surface
water diverted in the Nile Valley, the contribution from groundwater is most commonly on the
fringes of, or outside of, irrigation project command areas. Around 25 per cent of the total
volume allocated to irrigation is thought to contribute to return flow and groundwater
recharge via agricultural drainage and deep percolation. Management of groundwater is often
fragmented among different stakeholders which may include government agencies, NGOs,
farmer organizations, the private sector and investors, depending on the scale of the project. In
the newly settled areas around oases and other depressions in the desert, the water supply systems
on a subregional and local level include mesqas (small/tertiary canals used for water
supply and irrigation), wells (government and private), collectors and field drains.

In the newly settled areas of the Western Desert (west of the Nile), agriculture is mainly
dependent on groundwater abstracted through deep wells from the NSAS. Shallow aquifers in
the mid- and southern desert are contiguous with the deep aquifer providing potential for
further groundwater development, and there are plans to expand agricultural land around oases
in the western desert with irrigation from both shallow and deep wells. The main obstacles to
utilizing this resource are the great depths to the aquifer (up to 1500 m in some areas), and
deteriorating water quality at increasing depths. While development of groundwater in the NSAS is
naturally limited by pumping costs and economies of scale, there are also transboundary consid­
erations for this shared resource. This is formalized in a multilateral agreement between Egypt,
Libya, Sudan and Chad, and an extensive monitoring network exists under the auspices of
the newly settled areas around oases and other depressions in the Western Desert.

As noted above, groundwater abstraction is confined to shallow wells within the NSAS. Shallow
aquifers in the Nile Valley and Delta are considered nationally as a renewable
resources with extraction largely from shallow wells with a relatively low pumping cost. This
aquifer is considered as a reservoir in the Nile River system by the Ministry of Water
Resources, with a large capacity but with a rechargeable live storage of only 7.5 billion m³ yr⁻¹.
The current abstraction from this aquifer is estimated at 7.0 billion m³ in 2009 (MWRI, 2010).

Conjunctive use of surface water and groundwater is practised widely by farmers, especially
during periods of peak irrigation demand and at the fringes of the surface water irrigation
network, where groundwater can be the only source. In the Nile Delta areas, a distinction is
made between ‘old’ and ‘new’ lands facing a shortage of irrigation water. In the old land, the
main source of irrigation water is the Nile River but towards the end of irrigation canals,
groundwater is in many cases the only source. As the shallow aquifer is in hydraulic contact
with both the surface water irrigation system and the Nile River system, it can receive both
recharge and pollution from surface water sources and is therefore vulnerable. The aquifer is
also affected by programmes which reduce conveyance losses in waterways.

In the Eastern Desert (between the east bank of the Nile and the Red Sea) most ground-
water development is confined to shallow wells within wadi aquifer systems and to desalination
of groundwater. Total groundwater usage was estimated to be 3 million m³ yr⁻¹ in 1984 and the
current extraction rate is likely to be closer to 8 million m³ yr⁻¹. Potential for further development
is largely based on deep wells (200–500 m), accessing the NSAS and large wadis of the
Nile Valley and Lake Nasser catchments. There is also some potential for development of brackish
groundwater, especially in the Red Sea coastal areas.

In addition to agricultural and domestic use, industry in Egypt is also highly dependent on
groundwater. Factories may receive water from mains water supply system or their own wells.
A few small factories may depend on surface water from mesqas. The tourism sector generally
depends on the availability of water from desalination plants.

The major issues and problems summarized for groundwater management include:

- Lack of coordination and cooperation
- Inadequate institutional capacity to manage groundwater
- Poorly controlled groundwater management

As noted above, the shallow aquifer of the Nile Valley and Delta is considered nationally as a renewable
resource with extraction largely from shallow wells with a relatively low pumping cost. This
aquifer is considered as a reservoir in the Nile River system by the Ministry of Water
Resources, with a large capacity but with a rechargeable live storage of only 7.5 billion m³ yr⁻¹.
The current abstraction from this aquifer is estimated at 7.0 billion m³ in 2009 (MWRI, 2010).

In the Eastern Desert (between the east bank of the Nile and the Red Sea) most ground-
water development is confined to shallow wells within wadi aquifer systems and to desalination
of groundwater. Total groundwater usage was estimated to be 3 million m³ yr⁻¹ in 1984 and the
current extraction rate is likely to be closer to 8 million m³ yr⁻¹. Potential for further development
is largely based on deep wells (200–500 m), accessing the NSAS and large wadis of the
Nile Valley and Lake Nasser catchments. There is also some potential for development of brackish
groundwater, especially in the Red Sea coastal areas.

In addition to agricultural and domestic use, industry in Egypt is also highly dependent on
groundwater. Factories may receive water from mains water supply system or their own wells.
A few small factories may depend on surface water from mesqas. The tourism sector generally

The Nile River Basin

depends on the availability of water from desalination plants.
Overview of groundwater in the Nile River Basin

Depends on a mains supply from the government system; private wells also exist along with desalination plants in coastal zones for both groundwater and sea water purification.

Monitoring and assessment of groundwater resources

The major shortcomings associated with groundwater monitoring systems in the NRB are symptomatic of much of Africa as a whole (Foster et al., 2008; Adelana, 2009) and can be summarized as follows:

- Lack of a clear institutional/legal base and fragmented organizational responsibilities.
- Inadequate technical capacity and expertise, and lack of sustainable financing and resources to monitor and manage groundwater.
- Poorly coordinated groundwater development activities with little or no linkage to groundwater monitoring systems, and database management and retrieval systems.

As noted above, knowledge and data on groundwater use vary widely within the Nile countries but, in general, more information tends to be available in those countries which rely heavily on groundwater. All countries of the Nile are trying to improve their management of groundwater and this requires mapping of aquifers, groundwater monitoring, analysis of extraction and recharge rates, and proper data management. National efforts are also broadly supported by the research, NGO and donor community. The Groundwater Management Advisory Team (GW-MATE) of the World Bank Water Partnership Program has provided technical support throughout Africa over the last decade, and continues to do so, with very positive results (Tuinhof et al., 2011).

Despite the heavy reliance on groundwater for domestic supplies in Uganda, there is no national monitoring network in place, and this is needed as a matter of priority.

Throughout Ethiopia, relatively extensive hydrogeological field surveys provide sufficient information to classify the major aquifers and their characteristics (Ayenew et al., 2008). The Ministry of Water and Energy is now compiling an integrated database, the National Groundwater Information System (NGIS), which will replace the earlier ENGDA (Ethiopian National Groundwater Database) system hosted by the Ethiopian Geological Survey (EGS) and Addis Ababa University. Recent well-drilling campaigns for water in the Addis Ababa vicinity have revealed highly productive deep aquifers at more than 300 m and, in a number of cases, recent wells drilled up to 500 m have revealed highly productive artesian aquifers. It is likely that the aquifers close to urban and more developed areas, such as those near Addis Ababa, will be developed for agriculture and industrial uses in the near future. In some areas such as Gonder and Mekele over-extraction has already led to decline of the groundwater level (Ayenew et al., 2008). Careful monitoring and regulation are needed to prevent long-term negative impacts on groundwater resources by the inevitable expansion of groundwater utilization in the basin.

There is no systematic monitoring of groundwater recharge in Sudan. Localized investigations are usually performed on a case by case basis for a limited time period. Plans have been made for a nationwide observation network but they have not been implemented so far mainly due to lack of funding, coordination and recent civil unrest. Apart from urban centres, abstraction data are estimated and do not account for the numerous traditional wells. Therefore, actual abstraction is likely to be higher than the estimated volumes.

Egypt has a highly developed groundwater extraction network, and data on the distribution of wells have been compiled by several agencies over the past two decades, including the Ministry of Water Resources and Irrigation (Ramy et al., 2008; Table 10.6).
The Nile River Basin

Policy, regulation and institutional arrangements for groundwater resource management

The development of policies and the design of regulations and institutional arrangements are the first steps to managing and regulating groundwater. From this perspective of the Nile countries we have considered in this chapter, all have initiated this process to either a greater or lesser extent, broadly in line with their general level of economic development. The governments of Uganda and Ethiopia have a strong focus on domestic supply from groundwater as a most urgent concern, and are pushing ahead with policies expanding this service in both rural and urban areas, while Egypt has a well-established groundwater-fed domestic water supply system with associated regulation at different local levels, and plans for development and expansion of settlements which rely on conjunctive use of groundwater and surface water. In comparison, prior to separation, Sudan had established mandates for water policy generally, but to date in post-separation Sudan, especially South Sudan, there is no clear framework, with groundwater exploitation occurring on an ad-hoc and completely unregulated basis. Development organizations are also involved in the creation of frameworks for groundwater regulation and management to varying degrees across the NRB, and it is difficult to know the extent to which these frameworks are currently implemented (see section on Ethiopia below). As the countries we have considered are at quite different levels of policy development and implementation, more detail is provided below.

Uganda

Most groundwater utilization in Uganda is for domestic demand in both rural and urban areas. The Government of Uganda views the water sector as vital for poverty eradication, and by working with a number of development partners, it has set a target of providing safe water and sanitation for the entire population by 2025. Currently, water supply and sanitation rates for rural populations are 63 and 58 per cent, and for urban dwellers 68 and 60 per cent, respectively. Groundwater development is key to achieving this target and in the 1990s this began with the formation of the Rural Towns and Sanitation Programme, supported by the World Bank. The Ministry of Water and Environment implements this programme which is ongoing and has a high success rate in providing communities with domestic water from groundwater. Under this initiative 60 urban centres were identified for piped water supply (MWLE, 2006). By July 2006, 180 small towns had been included in the scheme for piped water supply. By that time 98 had operational water supply systems, 24 were under construction and 44 were at the design stage (MWLE, 2006). Out of the 98 operational water supply systems, 73 were based on groundwater from a total of 66 deep boreholes and 24 springs. At that time a further 684 small towns were identified to be provided with piped water during the next 15-year period, of which it is estimated that over 550 will be based on groundwater from deep boreholes (MWLE, 2006). The MWLE also regulates groundwater-fed wetlands and prevents destruction of habitat by conversion to agricultural land.

Ethiopia

In the past there was little recognition of the importance of groundwater in Ethiopia. The existing river basin master plans for example, which were developed for all the major basins of Ethiopia, include very limited groundwater data sets or analyses. However, recognition of groundwater is growing, and the Government of Ethiopia has determined to provide domestic water supply to all of its population by 2040. It is doing so by developing a demand-side management plan to build an enabling environment, so that the government-developed aquifer and surface water resources are used efficiently and sustainably. The plan has been designed with the involvement of relevant institutions at different levels in Ethiopia. The plan recognises the importance of enhancing the quality and quantity of surface water resources in Ethiopia. According to the plan, the main objectives include integration of the demand side, integrated water resources management, integrated aquifer management, integrated drainage, and integrated surface water resources. In addition, the Government has identified areas where groundwater is critical for its development. The federal government and involve in the development of the plan, and it is planned to be enforced, at the national level, by the Ministry of Water, Irrigation, and Energy. The plan is expected to be reviewed regularly, and institutional arrangements should be maintained to ensure that the plan is implemented effectively.

Stakeholder involvement is critical to the success of the plan, and the government has established a committee to oversee the development and implementation of the plan. The committee is responsible for ensuring that the plan is implemented effectively and that all relevant stakeholders are involved in the process. The committee is also responsible for ensuring that the plan is reviewed regularly to ensure that it is up to date and remains relevant to the needs of the country. It is expected that the plan will be reviewed regularly, and institutional arrangements should be maintained to ensure that the plan is implemented effectively.
Overview of groundwater in the Nile River Basin

water supply to 70 per cent of its population by 2015 as a key millennium development goal, primarily based on development of its groundwater resources (see Table 10.3). Working with GW-MATE, the Ministry of Water and Energy has developed its Strategic Framework for Managed Groundwater Development (MWR/GW-MATE, 2011). The framework aims to build an enabling environment with policy adjustments, regulatory provisions and user engagement, so that effective measures can be taken in managing groundwater quality and promoting demand-side as well as supply-side management. Within this framework action plans will be developed according to national and local priorities within the ‘resource setting’ (hydrogeological and socioeconomic) and using a range of management tools. At this stage the first action plan has been developed for the Addis Ababa region (MWR/GW-MATE, 2011). The government also recognizes groundwater as an instrument for economic growth and livelihood enhancement, with groundwater a major component in the ambitious target to increase the area under irrigation by six-fold by 2015 (MWR/GW-MATE, 2011).

According to the MWR/GW-MATE report, the most pressing policy issues are a stronger integration of groundwater development and land use planning, selection of target areas for intense groundwater development and combining groundwater development (both recharge, retention and reuse) with other water resource programmes, including watershed programmes, drainage, and floodplain development (MWR/GW-MATE, 2011). The framework highlights target areas with proven high reserves, high-potential areas with the most accessible aquifers and areas where climate change predictions indicate the need for supplementary irrigation. The MWR/GW-MATE report acknowledges the need to scale up regulation of groundwater, clarifying responsibilities and mandates of different organizations from federal and regional to river-basin level in the private and public sectors, to include the wide range of stakeholders involved in managed groundwater development. Currently, regulations exist but are rarely enforced, and mandates seem to overlap. The 1960 Civil Code established that groundwater is public property and strictly limits the development of private wells while the 1999 Water Resource Planning Policy provides a set of guidelines for water resources development. These regulations need to be enforced by an organization with a clear mandate, and individual cases should be incorporated within a broader development plan, locally and regionally. There is considerable scope for sustainable development of the resource in Ethiopia if the management measures included in Table 10.7 can be implemented.

Stakeholder participation, capacity-building and the promotion of private-sector capacity in addition to capacity within government departments are key to achieving all of the above institutional and non-institutional targets.

Sudan (North and South)

It is difficult to talk about groundwater policy and regulation without considering recent political events and the formation of two separate states of North and South Sudan in July 2011. Prior to separation there were four levels of government in Sudan (interim constitution 2005), all of which had water-policy making mandates:

1. The Federal (National Unity) Government with one ministry for water affairs and a draft water policy.
2. The Government of South Sudan (GOSS) with an approved water policy and three water affairs ministries.
3. The 26 State Governments each with, at least, two water affairs ministries.
4. The Local 'Magab' or council level.
Table 10.7 Proposed institutional responsibilities for the development and management of groundwater resources in Ethiopia

<table>
<thead>
<tr>
<th>Institution</th>
<th>Responsibility/Activity/Mandate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ministry of Water and Energy</td>
<td>Develop policies, standards and criteria for groundwater management plans; drilling standards and well design; fluoride/iodine treatment; maintain information base; initiate and support interregional groundwater management plans and oversee water allocation</td>
</tr>
<tr>
<td>Ethiopian Geological Survey</td>
<td>Plan and guide groundwater assessments</td>
</tr>
<tr>
<td>Federal Environment Protection Authority (EPA)</td>
<td>Review possible impacts of national investments on groundwater quality and quantity; strategic environmental assessments linked to groundwater management plans</td>
</tr>
<tr>
<td>Regional governments</td>
<td>Integrate groundwater management into other development programmes</td>
</tr>
<tr>
<td>Regional Water Resources Development Bureaus</td>
<td>Adopt policies, standards and criteria; initiate groundwater management plans for selected areas and supervise quality of monitoring; licensing in low-density areas</td>
</tr>
<tr>
<td>Regional EPA</td>
<td>Licensing in high-density areas (need to be upgraded); and review possible impacts of investments on groundwater quality and quantity</td>
</tr>
<tr>
<td>River Basin Organizations (need to be created)</td>
<td>Coordinate surface water and groundwater allocation and supply</td>
</tr>
<tr>
<td>Water user associations (need to be created)</td>
<td>Local regulation and efficiency measures; support and engagement in groundwater management plans</td>
</tr>
<tr>
<td>Well field operators</td>
<td>Monitoring</td>
</tr>
<tr>
<td>Universities</td>
<td>Monitoring</td>
</tr>
<tr>
<td>Universities management</td>
<td>Courses in drilling, drilling supervision and groundwater management</td>
</tr>
<tr>
<td>Technical and vocational education and training (TVETs), NGOs</td>
<td>Courses in manual drilling and pump development</td>
</tr>
<tr>
<td>Private-sector educational services</td>
<td>Specialist courses</td>
</tr>
<tr>
<td>Public-sector technical services</td>
<td>Design and supervision</td>
</tr>
<tr>
<td>Private-sector technical services</td>
<td>Design and supervision</td>
</tr>
<tr>
<td>Corporate private-sector drilling services</td>
<td>Drilling of shallow and deep wells (to be strengthened)</td>
</tr>
<tr>
<td>Artisanal private-sector drilling services</td>
<td>Drilling development of very shallow wells (to be strengthened)</td>
</tr>
</tbody>
</table>

Almost all the levels had identical empowerment but no institutional capacity, resulting in general confusion and widespread infringement of existing principles. Therefore, the Water Resources Act was passed in 1995 but remains unimplemented to date. This situation is further complicated by the recent formation of two states. The reinstatement of a legal framework is yet to be implemented and currently the development of groundwater resources in Sudan remains unregulated. Wells are drilled without permits or regulation, often close to septic pits dug for the disposal of wastewater.
Overview of groundwater in the Nile River Basin

the disposal of household sewage, and there is no accountability for any negative impact on the groundwater resources.

A further and major challenge faced by regulation of groundwater in North and South Sudan is the lack of accurate information on groundwater potential and the absence of quantitative and qualitative monitoring. The institution responsible for this (in the pre-separation Sudan) was an under-resourced, small department of the Ministry of Irrigation and Water Resources, mandated to provide both water resource management and water services. Almost the entire ministry budget is required to deliver irrigation and drinking water services. The significant potential for groundwater development is recognized regionally and there has been interest in investing in groundwater irrigation in the Nile, Northern, Central and Khartoum States, particularly from the Gulf States, but lack of coordination and clear regulation at this point has the potential to cause further conflicts.

Egypt

The challenge of managing scarce water resources, including groundwater, for sustainable development incorporating medium and long-term use for a range of stakeholders is recognized as priority by the Egyptian government. In most water resources management situations, some form of planning already exists, varying according to the resources in question, planning tradition, administrative structure and technical issues. The Ministry of Water Resources and Irrigation (MWRI) has a management plan which aims to address the challenges of water scarcity it considers to be of concern. In relation to groundwater, the plan highlights groundwater development for agricultural expansion into 'new' areas, relocating people from the Nile Valley and Delta to initiate new communities in areas currently desert. This will clearly intensify demands on groundwater.

In the 'Renewable Aquifer Underlying the Nile Valley and Delta' the MWRI plan focuses on the conjunctive use of surface water and groundwater by:

1. Utilizing aquifer storage to supplement surface water during peak periods and artificially recharging the groundwater during the minimum demand periods.
2. Employing sprinkler or drip irrigation from groundwater in the 'new lands' to prevent waterlogging and rising water tables.
3. The use of vertical well drainage systems in Upper Egypt to prevent waterlogging and rising water tables.
4. Utilizing groundwater for artificial fish ponds (high quality and consistent temperature).
5. Pumping groundwater from low-capacity private wells at the end of long mesqas to supplement canal water supply.

In the deep aquifers of the Western Desert (and Sinai), which require a large investment to be viable, future strategies outlined in the plan include:

1. Intensive survey to determine the main characteristics of each aquifer including its maximum capacity and safe yield, and monitoring to prevent abstraction beyond sustainable yields.
2. The development of new small communities in the desert areas designed to use all available natural resources through integrated planning.
3. Utilizing renewable energy sources, including solar and wind, to minimize the pumping costs.
4. Application of new irrigation technologies in desert areas minimizing losses, especially deep percolation due to the high porosity.

If implemented, all of these strategies would help to reduce pressure on increasing demand for groundwater. However, at this stage the plan is on paper and subject to investment finance.

The Egyptian government is also considering the use of the brackish groundwater (3000-12,000 mg 1-1 TDS), such as is found at shallow depths in the Western and Eastern Deserts and at the fringes of the Nile Valley following desalination treatment. Renewable energy sources are proposed to reduce the cost of the treatment process, with the resulting ‘fresh’ water used for supplemental irrigation of a second-season crop.

Overall, future strategies and policies for groundwater development assessment and utilization identified by the MWRI plan include:

1. Utilization of technologies from the water resources management sector, especially remote sensing and GPS techniques; numerical modelling of groundwater and surface water models; information and decision support systems to integrate the ministry’s water resources information; use of geophysical methods (e.g. electromagnetic and electrical resistivity, and use of environmental isotopes).
2. Water quality monitoring and management to prevent transport and contamination by pollutants.
3. Raising awareness with the general population and with policy-makers, of water resource issues and achievements in water management, via the media and by demonstration of positive water saving consequences, achieving public participation and commitment of policy-makers to water policies and programmes; increasing knowledge and capacity on new technologies to conserve water in irrigation and domestic use.
4. Continuous monitoring and evaluation to enable strategic adjustments needed to correct deviations from the original objectives.
5. Coordinating and enabling different water users and water-user groups.
6. Institution building and strengthening, linking the public and private sectors, transferring knowledge and human resources within the water sector; providing management training and technical skills.
7. Strengthening coordination between ministries to avoid overlapping mandates, and enhance exchange of data, knowledge, experience and technical expertise in the different field of water resources between different authorities.
8. Providing a detailed review of all existing water resources laws and decrees and their relation to water management to ensure that up to date laws and regulations reflect the long-term objectives of water resources management.
9. International cooperation – in the case of groundwater this particularly refers to the NSAS, shared by Chad, Egypt, Libya and Sudan.
10. Ensuring that the planning and policy formulation process is based on the most up to date research and development outcomes and comprehensive planning studies.

Overall and individually, these strategies are highly desirable for the sustainability of the groundwater resources. It can only be hoped that the plans can be implemented.

In considering the information provided above, it is useful to note that the groundwater resources of the NRBB, like the river itself, do not conform to national and other political boundaries. Wise management of groundwater requires governments and related agencies to work together to achieve sustainable utilization of this often shared resource.
Overview of groundwater in the Nile River Basin

Conclusions

Large parts of the NRB are prone to high rainfall variability and seasonal and periodic droughts. Further, climate change predictions indicate that this situation may worsen. It is broadly accepted that groundwater can provide some degree of buffering to this threat, supplementing surface water supplies, reducing risk and strengthening resilience, and reducing the vulnerability of the poor to water shortages. In fact, adequate reliable water supplies are essential to economic development at all levels. It is increasingly acknowledged that wise management of groundwater resources can provide this security. In addition, increasing water stored in this reserve during times of high rainfall by actively diverting surface water to ground-water recharge can support sustainable groundwater use.

There are many challenges facing sustainable management of the groundwater resources of the NRB. With the exception of Egypt, most of the ten countries are relatively undeveloped in terms of industry and commercial agriculture and the role of groundwater is primarily for the provision of domestic supplies. This will change in the future, and so the demand for water from groundwater for these uses will increase. Africa’s population is growing rapidly and the 1999 population of 767 million is projected to nearly double by 2035 (UNFPA, 2011). Although fertility rates do differ across the continent, these predictions are largely applicable to the NRB, with obvious implications for domestic use, the consumption of water for increased food-agriculture demand, and all other high-water-demand and human-related activities. In parts of the basin where surface waters are already severely stressed, such as Egypt, growing populations pose a severe challenge for groundwater management. In Egypt’s case, the authorities are already relying strongly on groundwater to meet the needs of new communities in marginal areas and to relieve pressure on surface water in more densely populated areas close to the Nile River.

In parallel to industrial and commercial development, the building and strengthening of governance and regulatory structures are also in an early stage of development in many Nile countries. Generally, natural resources policies and regulations can be seen to lag behind other sectors (such as law and health). Many countries have developed policies and strategic frameworks, often with outside help (e.g. Ethiopia and GW-MATE), but implementing the policies may take several more years. Naturally, without clear mandates and regulatory structures, monitoring and planning cannot be well implemented. While the importance of sustainable management of groundwater is now broadly acknowledged within the NRB, conjunctive management of groundwater and surface waters is some way off.

References


Overview of groundwater in the Nile River Basin


